

# **Dynamically Constrained Nowcasting in the Coastal Ocean**

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## **LONG-TERM GOALS**

Our long-term goal is to better understand ocean interactions at various space and time scales by quantifying submesoscale processes. We focus on the following four areas:

- Understanding small-scale coastal ocean processes;
- Understanding small-scale advective exchange and stirring;
- Model assessment, enhancement, and assimilation;
- Using high-resolution disparate (HRD) ocean surface data to infer subsurface flow conditions.

## **OBJECTIVES**

Our objective is to combine disparate observations from various sensors (HF radar, Lagrangian drifters, current meters, ADCPs, passive remote sensing, etc.) to develop dynamically consistent nowcasts of the surface velocity field. Open boundary flow information from any source (observations, models, climatology, etc.) can be used if needed. The nowcasts can be used to understand coastal processes (including inferences about the subsurface flow) or can be assimilated into a numerical model. Dynamical systems templates can also be applied to the nowcast to study mixing and exchange.

## **APPROACH**

We use a spectral technique called normal mode analysis (NMA), a generalization of a method first described by Rao and Schwab (1981) in an analysis of currents in Lake Ontario. Numerically

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generated basis function sets of both vorticity and divergence modes are used to blend disparate data sources into a surface velocity nowcast. The NMA method is described by Eremeev *et al.* (1992a), and several oceanographic applications are discussed in Eremeev *et al.* (1992b), Eremeev *et al.* (1995a,b), Lipphardt *et al.* (1997) Cho *et al.* (1998), Lipphardt *et al.* (2000), Schulz (1999) and Hunter (2001). This approach has several attributes which make it well suited for coastal ocean studies and rapid environmental assessment situations:

- Its spectral character readily admits data from disparate sources;
- Any arbitrarily shaped domain (including islands) can be analyzed;
- The spatial basis set can be calculated to arbitrary accuracy independent of the data;
- Open boundary information from any source can be easily blended with observations;
- The nowcast velocity field is three-dimensionally incompressible.

## **WORK COMPLETED**

We have completed most of the work on our first proposed task involving small-scale coastal process studies. A nearly continuous six-month time series of HF radar surface current measurements in Monterey Bay has been analyzed using the NMA nowcast method.

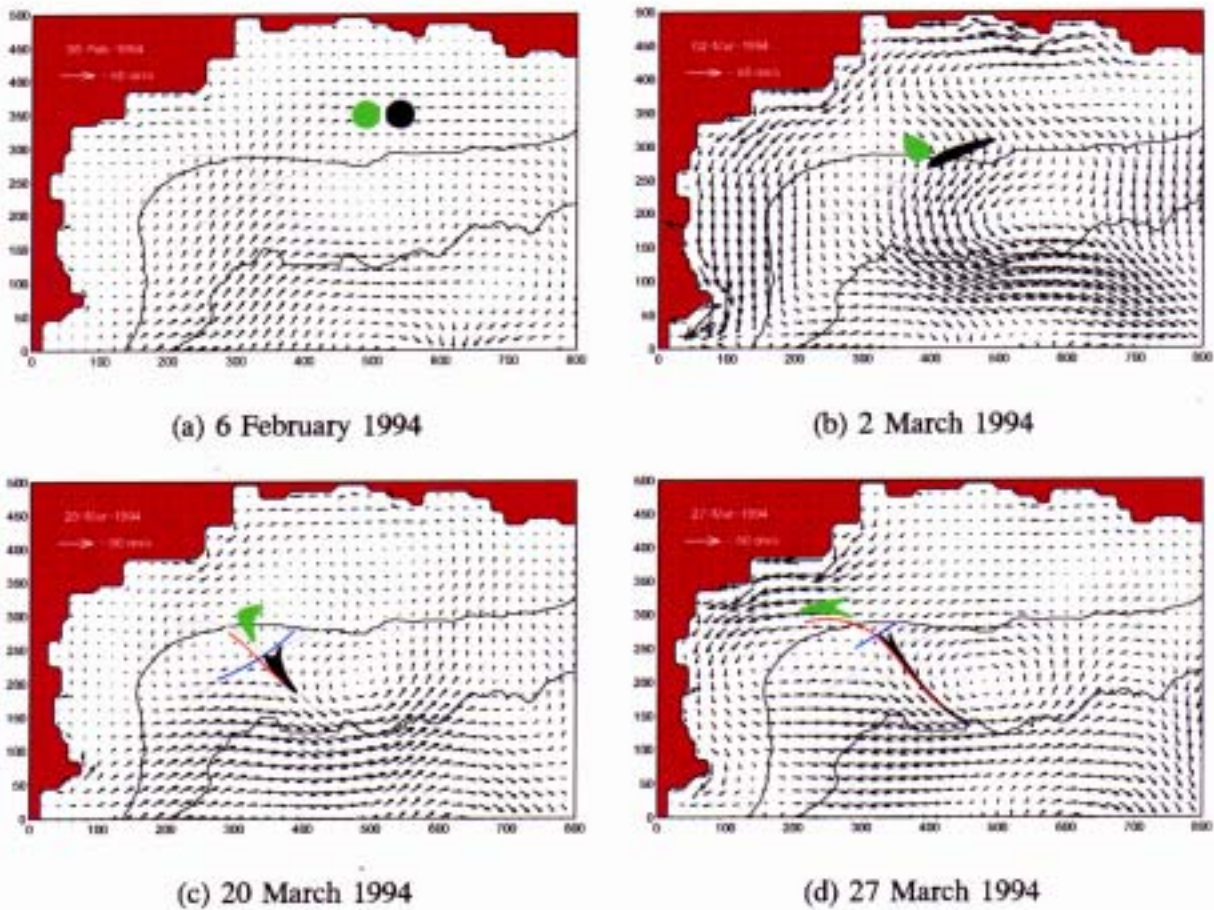
We have also completed a significant portion of the work on our second proposed task involving the study of small-scale advection and stirring. A student's M.S. thesis was published in the summer of 2001 (Hunter, 2001) describing robust mixing properties of the Louisiana-Texas shelf surface current field mapped using the NMA technique. Simple ideas from dynamical systems theory were applied to the mapped field to identify critical mixing structure in the velocity field.

## **RESULTS**

A nearly continuous record of hourly HF radar measurements in Monterey Bay for the period June 1999 through January 2000 was analyzed using NMA. A combination of spatial and temporal filtering was used to reduce noise apparent in the observations. Spectral analysis of the NMA mode amplitudes revealed energetic diurnal and semidiurnal peaks, likely due to the combined effects of wind and tides. Also apparent were significant spectral peaks in the 2-10 day band. Particle studies using the nowcast velocity field reveal a rich mixing structure inside the bay, with residence times for the surface layer that can be longer than one week.

On the Louisiana-Texas shelf, a combination of surface drifters, current meters, and model velocities from the U.S. Navy Modular Ocean Data Assimilation System (MODAS) was used to nowcast the surface velocity field for the period 8 December 1993 through 30 March 1994. Simple dynamical systems ideas were applied to this nowcast archive to identify stagnation points in the surface velocity field that were likely to lie near mixing boundaries in the flow. This analysis identified one persistent mixing boundary for the period 14-27 March 1994 near the shelf break off the Texas coast. A

distinguished hyperbolic trajectory was located, and inflowing and outflowing manifolds were identified. A series of particle studies was performed to investigate the flow field behavior in the vicinity of this mixing boundary.



**Figure 1. Evolution of two blobs of fluid parcels (shown in green and black) on the Louisiana-Texas shelf for the period 6 February through 27 March 1994. The inflowing (blue) and outflowing (red) manifolds are shown in panels (c) and (d). Note that when the blobs encounter the manifolds, they separate and rapidly stretch along the outflowing manifold.**

Our research has also identified a new problem area for modelers: boundary conditions at the coastline. Traditionally, ocean modelers have not paid much attention to the coastline since their areas of interest were several kilometers seaward. As a result, numerical procedures like staggered grids and no slip boundary conditions are often used to simplify the interior computations at the expense of boundary physics. Staggered grids produce some ambiguity about the precise coastline location, while no slip conditions do not account for well established physical processes in the coastal ocean.

With increased scientific and military attention focused on the coastal ocean, this situation is becoming untenable. Consequently, over the past year we have devoted some effort to adapting the NMA nowcast methodology to better account for coastline physics. One important development has been a numerical implementation that ensures no normal flow at every coastline gridpoint on a Cartesian grid. In principle, this should be readily extendable to staggered grids and to grids that use a spline coastline boundary.

## **IMPACT/APPLICATIONS**

We have demonstrated that the NMA technique is computationally inexpensive and can be applied to a wide variety of disparate data sets. It naturally enforces three-dimensional incompressibility and appropriate boundary conditions, making it an attractive choice for many rapid environmental assessment situations.

## **TRANSITIONS**

The involvement of graduate students in this research effort has proved to be an excellent way to begin transitioning the NMA technique for wider use. Two graduate students completed their degrees while pursuing research related to this effort. LCDR William Schulz completed his PhD dissertation in 1999 and studied surface currents on the Louisiana-Texas shelf using NMA (Schulz, 1999). Eli Hunter completed his M.S. thesis by extending the Schulz 1999 work, examining the mixing and exchange characteristics of the Louisiana-Texas shelf surface velocity field (Hunter, 2001).

## **RELATED PROJECTS**

There is considerable interaction with an ONR supported DRI entitled *Enhanced Ocean Predictability Through Optimal Observing Strategies*. That effort uses the NMA methodology to explore sampling strategies on a regional ocean scale using templates based on dynamical systems theory. We have access to a state of the art Gulf of Mexico model and concurrent drifter data. The drifters are used for model assessment.

We also maintain collaborations with scientists from the University of Bristol, Caltech, the Naval Postgraduate School, and the University of Southern Mississippi.

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